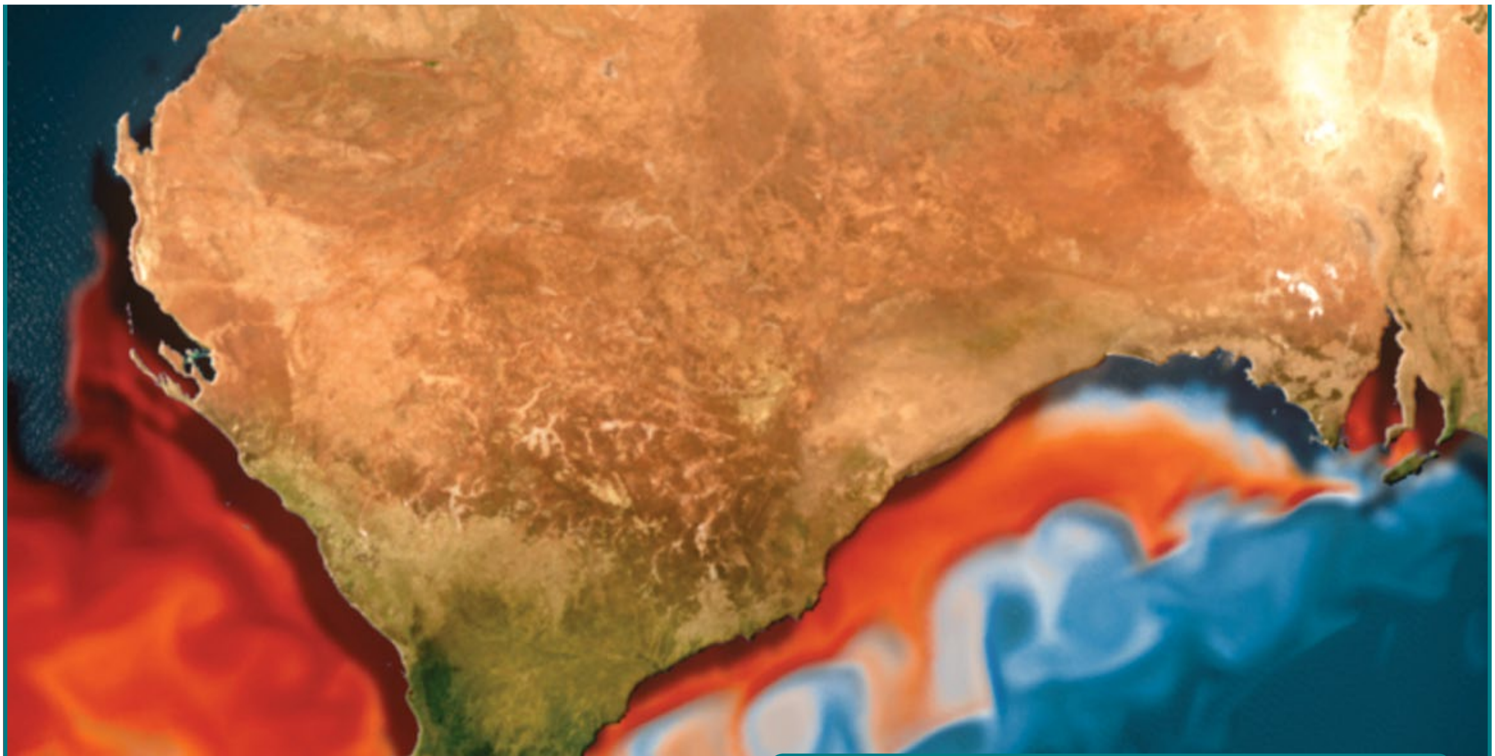
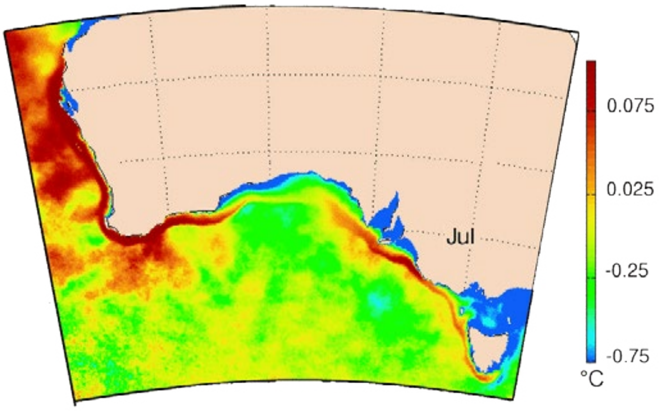
Government of **Western Australia**
Department of **Fisheries**

Fish for the future

IN DEPTH

LIVING WITH THE LEEUWIN CURRENT





Sea surface temperature satellite image showing the track of the Leeuwin Current from North West Cape to Tasmania. Illustration: CSIRO.

Introduction

The Leeuwin Current is arguably one of Australia's most influential natural features. It has a profound impact on the make-up of our marine ecosystems, species' lifecycles, fisheries and even our climate.

At 5,500 kilometres, the Leeuwin Current is the world's longest continuous coastal or boundary current. Originating at North West Cape, it flows southwards along the West Australian coast before curling eastward around Cape Leeuwin and flowing all the way to Tasmania.

Although the ocean current was formally identified and named in 1980, marine scientists are still discovering its dynamics and complex nature. Evidence is showing that the Leeuwin Current's strength and characteristics are changing, challenging our understanding and management of the marine environment and fisheries that occur in its large area of influence.

Discovery Piece by Piece *(History)*

As early as 1897, the naturalist William Saville-Kent observed the presence of tropical marine animals and plants at the Abrolhos Islands and noted that the water temperature there was several degrees warmer than that of the coastal waters at Geraldton. He speculated that this temperature difference was caused by an offshore southward-flowing tropical current.

It wasn't until the introduction of satellite imaging and studies using drifter buoys in the 1970s that the presence this current, running down the Western Australian coast to Cape Leeuwin, was finally confirmed.

In 1980, researchers George Cresswell and Terry Golding from Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) named the current, after the Dutch merchant sailing ship *Leeuwin* which explored the Western Australian coast in 1622.

A replica of the sailing ship Leeuwin *has been operating from Fremantle as the vehicle for a youth development program since 1986.*

In 1988, Alan Pearce and Bruce Phillips identified the link between the El Niño/La Niña weather events in the Pacific and the strength of the Leeuwin Current as well as the current's importance to the larval phase of the western rock lobster, affecting how many lobster juveniles settle on the coast.

In 2004, CSIRO researchers Ken Ridgway and Scott Condie were able to link together what had been thought to be three separate coastal currents into the single feature of the Leeuwin Current.

Researchers across many science-based organisations maintain an on-going monitoring program on the currents off the coast of Western Australia, using satellite sea-surface-temperature and sea-surface-height measuring devices, drifter buoys, onboard sampling by ships and moored instrumentation.

Characteristics of the Leeuwin Current

The Leeuwin Current is a southward-flowing boundary current that originates to the north of the North West Cape in Western Australia and flows down the entire west coast.

At Cape Leeuwin, the current turns eastwards and increases in speed, flowing along the south coast of Western Australia and across the Great Australian Bight before finishing at South Cape in southern Tasmania.

It is a surface current, present to a maximum depth of around 300 metres and generally following the edge of Australia's continental shelf. Where the continental shelf becomes narrow, such as along the Ningaloo Reef and Shark Bay coasts, the Leeuwin Current can be as little as 10 kilometres offshore. It is quite a slender band of water, not exceeding 100 kilometres in width.

The fact that the Leeuwin Current transports warm, tropical low-nutrient water in a southerly direction is unusual as, in general, surface currents in the southern hemisphere along the west coasts of continents flow northwards – for example, the Benguela Current (Africa) and the Humboldt Current (South America).

These two currents move towards the Equator and, in a process called upwelling, draw cold nutrient-rich water from the depths of the ocean to the surface. These upwellings contain large quantities of phytoplankton and zooplankton that provide food for very large numbers of small pelagic fish, such as pilchards and anchovies, which in turn are a food source for larger pelagic fish. As a result, the Benguela and the Humboldt support some of the world's most productive fisheries.

In contrast, instead of promoting the upwelling of deep nutrient-rich waters like the Humboldt and Benguela, the Leeuwin Current actually suppresses most of the upwellings along the west and south coasts of Western Australia. As a result, the current is made up of warm, low-nutrient water.

The result of this difference in nutrients between the Leeuwin and the Humboldt/Benguela is stark in terms of the numbers of pelagic fish they produce. This is graphically illustrated in a table compiled by Dr Rod Lenanton and Drs Lindsay Joll, Jim Penn and Ken Jones in a paper they wrote for the Royal Society of Western Australia, published in 1991[1].

In the 1980s, the annual commercial catch of finfish from the Humboldt was reportedly up to 13 million tonnes while the Benguela was up to four million tonnes. The catch from the Leeuwin off the West Australian coast was less than 1,000 tonnes! What this means practically is that the commercial catch of finfish in the proximity of the Humboldt current is 13,000 times larger than that in the proximity of the Leeuwin – simply because the former is naturally greatly more productive and thus has relatively huge fish stocks.

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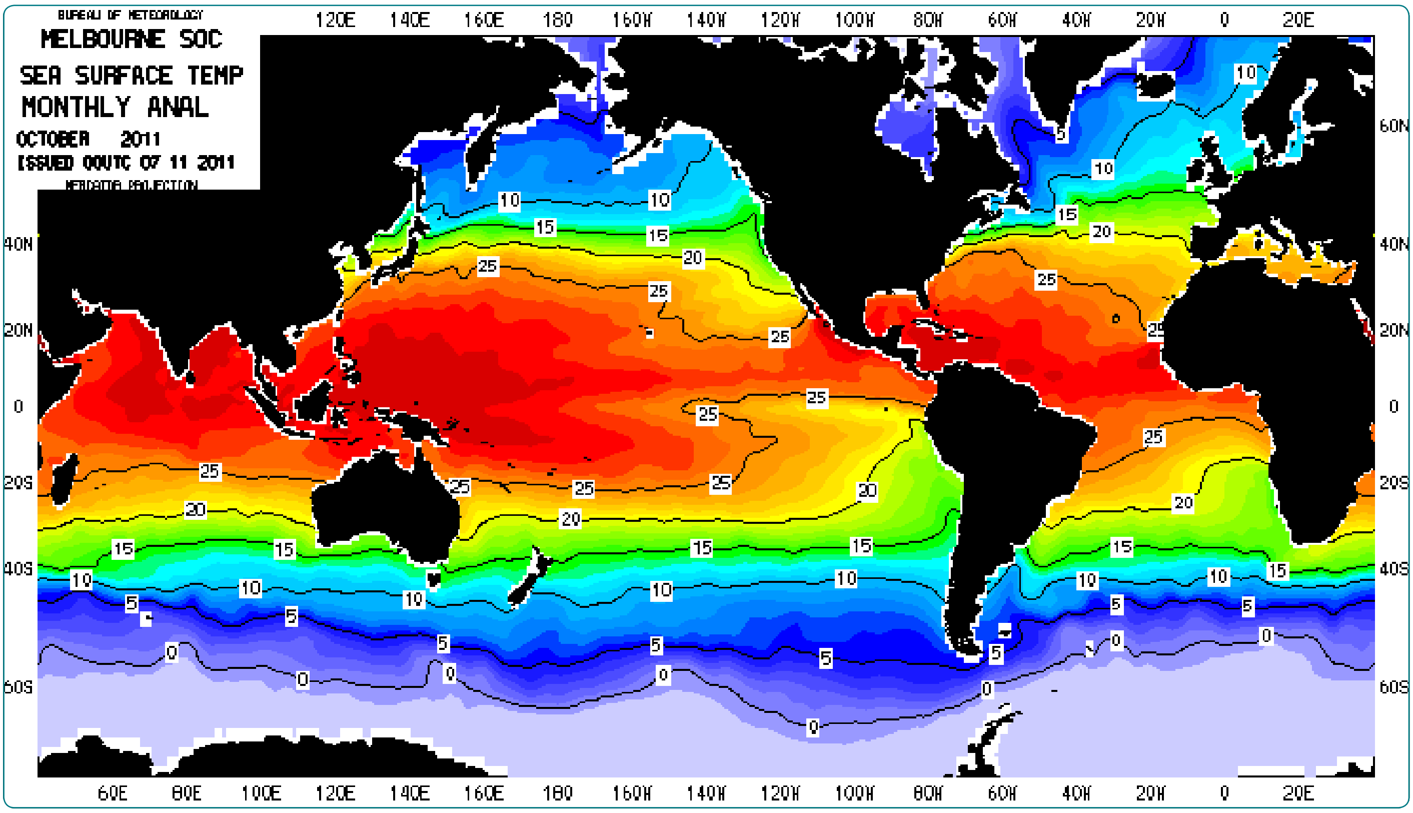
1 *'The influence of the Leeuwin Current on coastal fisheries in Western Australia', by R.C. Lenanton, L. Joll, J. Penn and K. Jones, Journal of the Royal Society of Western Australia, 74, 1991, 104-114*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Sea-surface-temperature images showing the cooler northward-flowing currents operating off the west coasts of South America (Humboldt) and Africa (Benguela). Off the west coast of Australia, the offshore waters are relatively warm in comparison, owing to the Leeuwin Current. http://www.bom.gov.au/products/IDYOC048.shtml

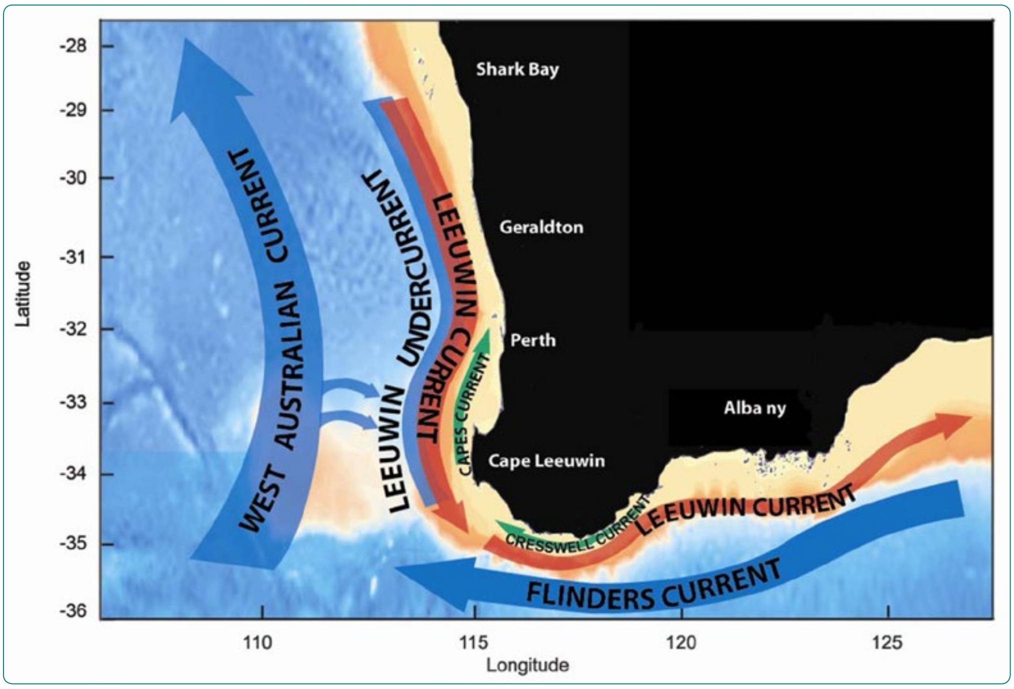
The Source

The driving force of the Leeuwin Current lies in the Pacific Ocean. Here, south-east trade winds cause warm low-salinity water to move westwards along the South Equatorial Current. When the current reaches Australia, the waters either turn southwards to create the East Australian Current or are pushed through the archipelago of Indonesia in what is referred to as the ‘Indonesian Throughflow’. The strongest flows usually occur between February and June.

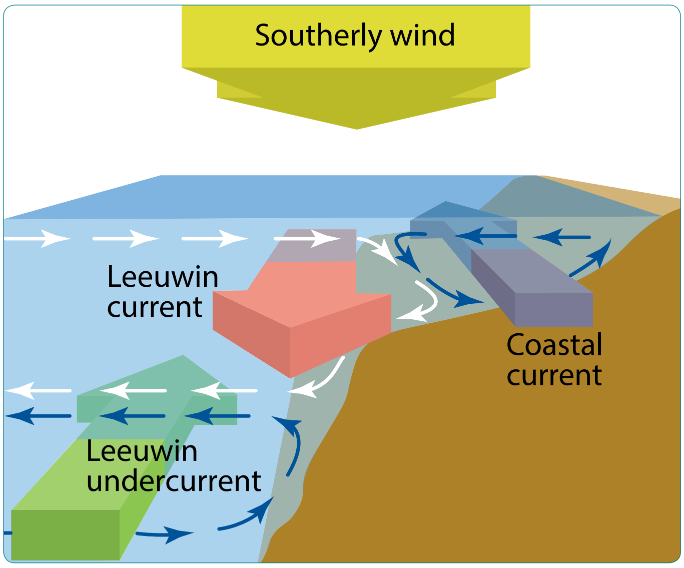
The warm, low-salinity water from the Indonesian Throughflow has a lower density than the waters to the south of Western Australia. This creates a difference in sea level of approximately half-a-metre between North West Cape and Cape Leeuwin. The Leeuwin Current flows down this gradient from high-to-low, not unlike a river.

System of Currents

Off the west and south coasts of Western Australia, there is a system of currents flowing in different directions. In addition to the Leeuwin Current operating at the surface, there is the Leeuwin Undercurrent, which travels northwards along the continental shelf at a depth of between 300 and 800 metres, carrying higher salinity and oxygen rich-water from sub-Antarctic areas.



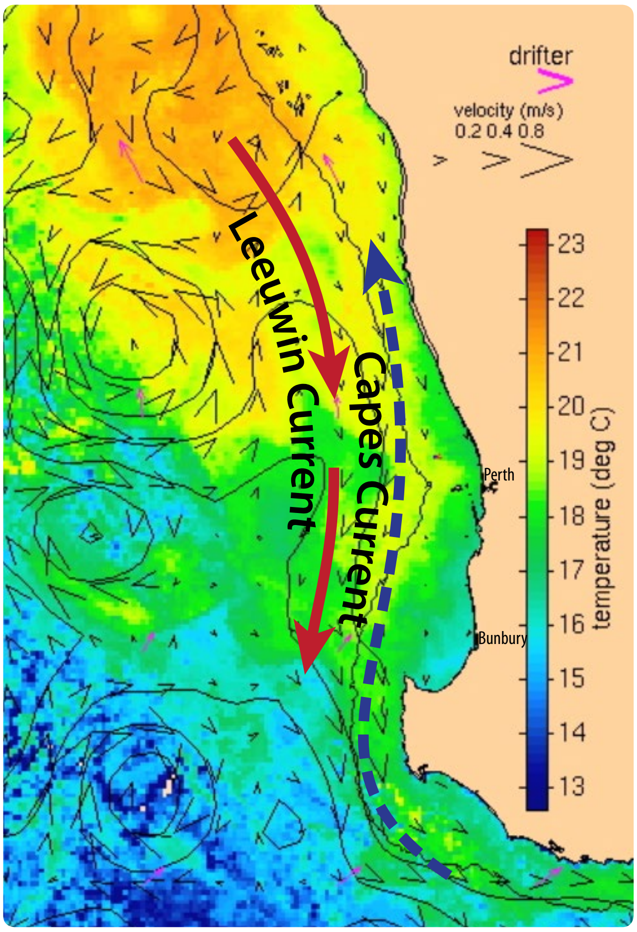
Schematic of the major surface and sub–surface current systems along the south-west region of Western Australia development program since 1986. (Pattiaratchi, C. , Science and Implementation Plan for the West Australian Integrated Marine Observation System (WAIMOS), Oct. 2008.)



Schematic diagram illustrating the general flow patterns at the continental margin of south-western Australia. (Woo and Pattlaratchi, 2008)

During the summer months in waters on the continental shelf, persistent southerly winds cause northward-flowing coastal currents, such as the Capes Current and the Ningaloo Current, to develop inshore.

The Cape Current originates near Cape Leeuwin and flows along the coast beyond Rottnest Island. This current promotes mild upwelling in areas near Cape Mentelle (Margaret River) and west of Rottnest Island (near the area of the Perth Canyon).

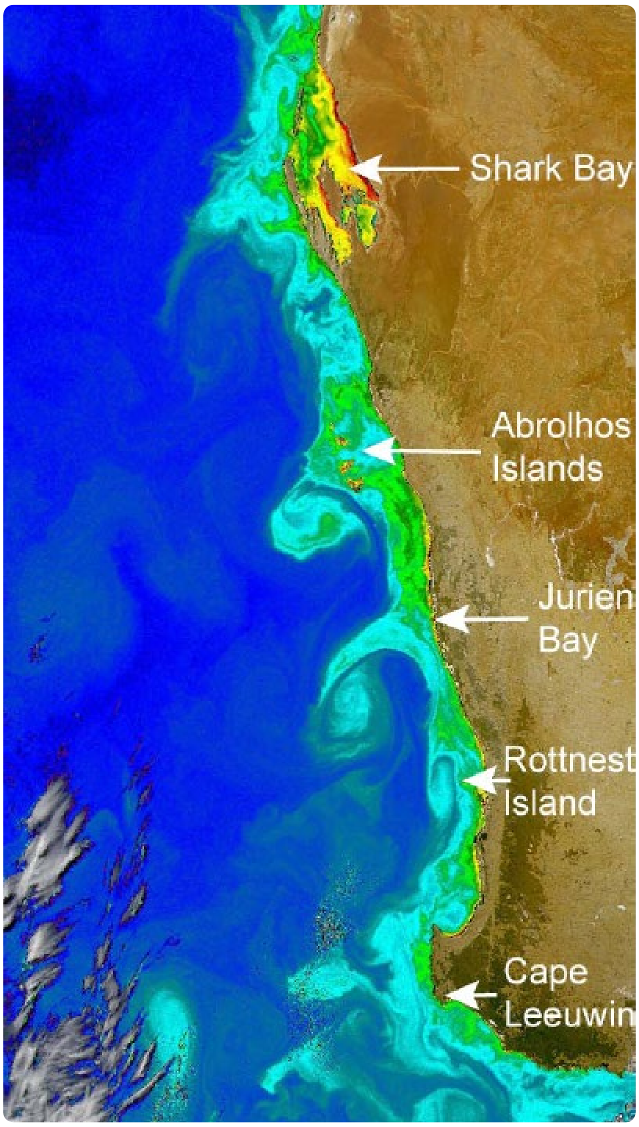


In late spring the Leeuwin Current moves a little offshore and, with the onset of strong southerly winds, is replaced by the Capes Current. The Capes Current dies away in about March/April. (Illustration: CSIRO.)

Eddies (Swirls and Curls)

Although the Leeuwin Current tends to flow southward along the edge of the continental shelf (for example, at the 200-metre depth contour), it periodically meanders offshore – rather like a river – in the form of loops and eddies. These circular jet-like currents can be quite large and intense, and tend to form in locations such as outside of Shark Bay, the Abrolhos Islands, Jurien Bay, Rottnest Island and Cape Leeuwin.

The behaviour and characteristics of eddies in the Leeuwin Current are a current focus of marine scientific research, as they are believed to play a major role in carrying fish larvae away from – or back towards – the coast and may represent areas of higher productivity.



Ocean colour image showing the eddy structure of the Leeuwin Current. The higher chlorophyll water is located on the shelf and is entrained into the Leeuwin Current. (Pattiaratchi, C., Science and Implementation Plan for the West Australian Integrated Marine Observation System (WAIMOS), October 2008.)

Seasonal Variation/Speed

The Leeuwin Current flows year-round, but at times against prevailing southerly winds. When these southerly winds strengthen between October and March, they cause the Leeuwin to weaken significantly. Conversely, when the winds subside between April and September, the current strengthens.

It is very difficult to directly measure the strength of the Leeuwin Current on a regular basis. The mean monthly sea level off Fremantle is used as an approximate gauge of the strength of the Leeuwin Current, with higher sea levels indicating a stronger current.

The average speed of the Leeuwin Current and its eddies is between 1 and 2 knots. Along the west coast the amount of water transported by the Leeuwin Current ranges between one and seven million cubic metres per second.

Interannual variability – ENSO Events

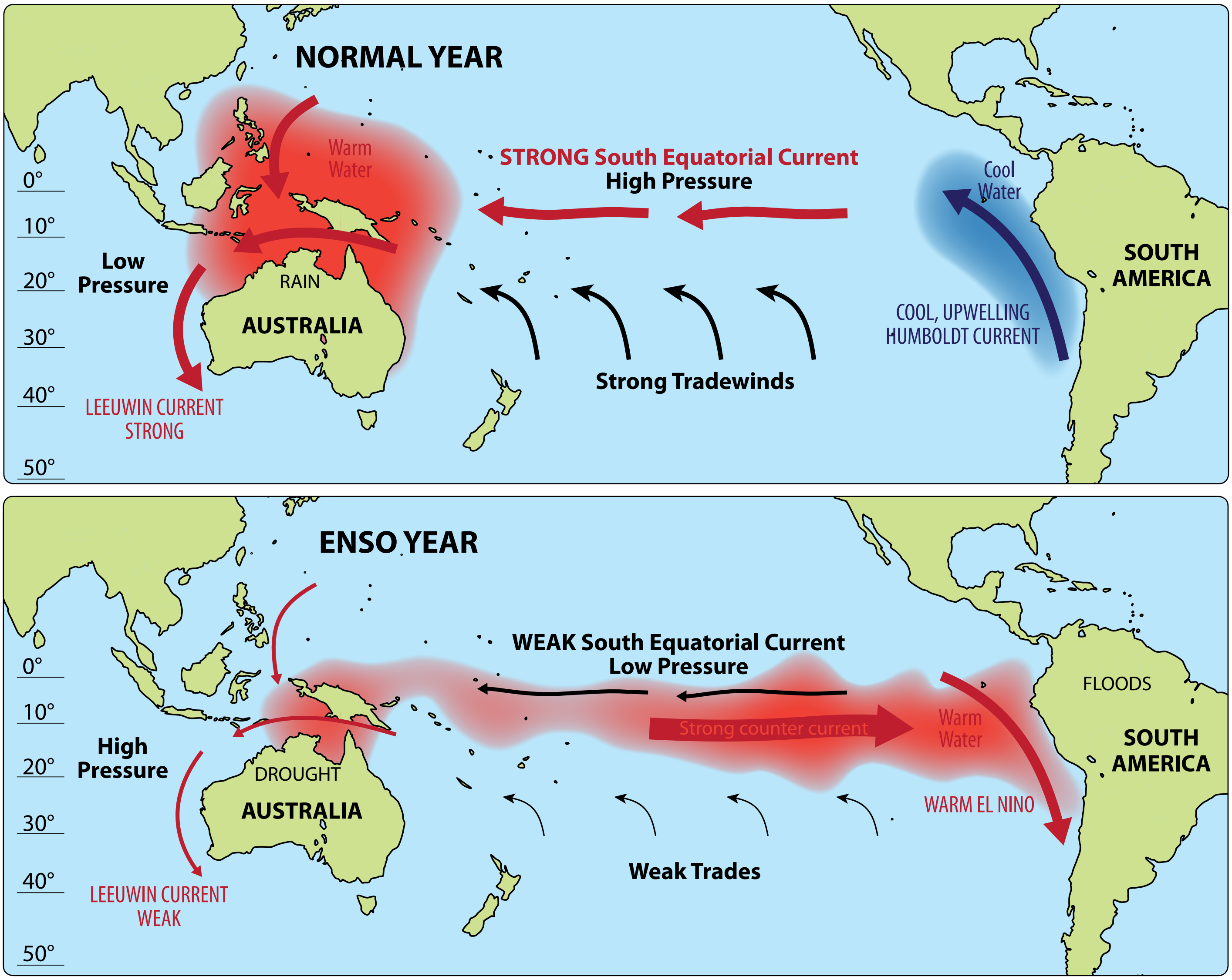
Fluctuations in the strength of south-east trade winds in the Pacific Ocean can have a dramatic effect on the strength of the Leeuwin Current.

Under normal conditions, called *La Niña* (Spanish for “little girl”), the atmospheric pressure off northern Australia is lower than that of the central-south Pacific Ocean. This pressure difference drives the south-east trade winds and forces the South Equatorial Current to flow westwards towards Australia.

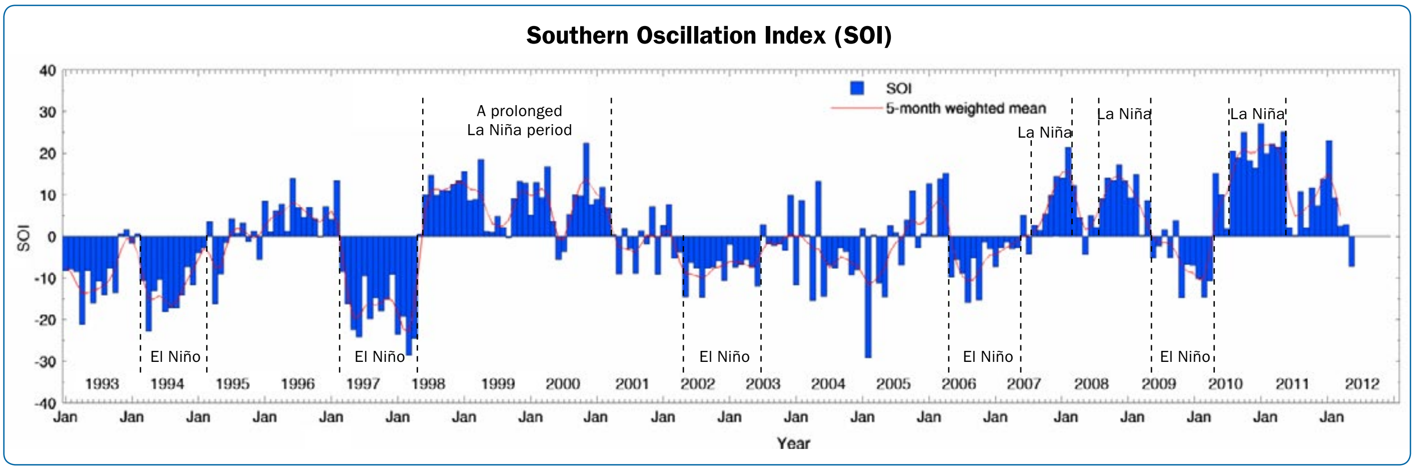
On occasions (between two to seven years), the atmospheric pressure difference weakens or even reverses between northern Australia and central South Pacific Ocean. This ‘see-sawing’ of the pressure is known as the ‘Southern Oscillation’.

During these weakening or reversing conditions, a southward-flowing warm current known as *El Niño* (Spanish for “little boy”) develops along the west coast of South America and displaces the cooler northward-flowing Humboldt Current. This spells disaster for the normally lucrative and productive fisheries off Peru because the current reversal associated with *El Niño* suppresses nutrient upwellings.

Meteorologists have joined the two linked environmental phenomena together with the name ‘El Niño/Southern Oscillation (ENSO) event’. Meteorologists attempt to predict ENSO events by monitoring the atmospheric pressure difference between Darwin and Tahiti through the Southern Oscillation Index. *La Niña* is the positive phase of the Southern Oscillation Index, while *El Niño* is the negative phase.



Normal year (top): Normally, the trade winds and strong equatorial currents flow towards the west. At the same time, an intense current, known as the Humboldt Current, causes upwelling of cold water along the west coast of South America. ENSO year (bottom): Upon the advent of an ENSO event, the pressure over the eastern and western Pacific flip-flops. This causes the trade winds to diminish, leading to an eastward movement of warm watr along the equator. As a result, the surface waters of the central and eastern Pacific warm, with far-reaching consequences to weather patterns.



Graph showing the values of the Southern Oscillation Index between 1993 and 2011, noting the La Niña and El Niño phases.

During *La Niña* events the Leeuwin Current is stronger while during *El Niño* phases, the Leeuwin Current is weaker.

Influence on Marine Life

The Leeuwin Current has a profound impact on the characteristics of our marine ecosystems, species life cycles, and our fisheries.

Dispersal of Eggs and Larvae

The Leeuwin Current is responsible for the southwards transportation of eggs and larvae of tropical and subtropical marine species. It allows marine ecosystems along the west and south coasts of Western Australia to support a unique composition of both tropical and temperate species.

Mass coral spawning at Ningaloo Reef corresponds with the intensification of the Leeuwin Current in March each year.

True corals can thrive at the Abrolhos Islands off the coast of Geraldton, making the area the southernmost true coral reef systems in the world. The corals co-exist with a high diversity of macroalgae and seagrass.

The marine ecosystem at the Abrolhos Islands 60 kilometres offshore of Geraldton has a unique composition of both tropical and temperate species.

Further south at Rottnest Island, over 130 species of tropical fish have been observed, compared to just 11 species in the cooler nearshore waters of Perth. At least 25 species of hard corals are able to survive in the reefs around Rottnest Island.

The western side of Rottnest, bathed in the flow of the Leeuwin Current, is an important settlement area for tropical marine species. Most of these recruits arrived as eggs or larvae, originating from areas such as the Ningaloo Reef and Abrolhos Islands. Water temperatures at Rottnest are too cold for the majority of these species to survive to adulthood and/or successfully breed so their populations are reliant on the Leeuwin Current to continually replenish them.

Interestingly, the eastern side of Rottnest Island misses out on the major influence of the Leeuwin Current and, as a result, exhibits a distinctly different species composition to that of the west.

Parker Point, Rottnest Island.

Marine species, such as the humpback whale, species of turtles and southern bluefin tuna, use the southern flow of the Leeuwin Current to their advantage in migratory patterns.

Photo: Barbara Kidd

After giving birth in tropical waters, humpback whales migrate using the Leeuwin Current to reach rich feeding grounds near the Antarctic.

Limited Nutrients

The Leeuwin Current's southward flow suppresses major upwellings, leading to nutrient-poor coastal waters along the west and south coast of Western Australia. Western Australia's geologically-old land mass and lack of major river systems also contribute relatively little in the way of nutrients that pass from the land to the ocean.

Marine ecosystems have successfully evolved to adapt to these low nutrient conditions. Clear waters with excellent light penetration support a high benthic productivity of seagrasses, macroalgae and corals. Coastal waters lack large stocks of finfish and instead favour a populous and diverse range of marine invertebrates, with their opportunistic scavenging and filter-feeding abilities. For instance the western rock lobster fishery is traditionally the largest single-species fishery in Australia.

Ecosystem Function

The abundance and breeding patterns of seabirds are influenced by the variations in the Leeuwin Current. The seabird's diets consist of juvenile and larval fish, so in years of depleted abundance of this prey there is likely to be a detrimental effect on seabird breeding patterns and success. Seabirds such as albatrosses and shearwaters ('mutton birds') are very long-lived so must cope with these Leeuwin Current variations in order to survive.

Photo: Michael Burgess

Albatross.

Influence on Fisheries

Recognising the effect of the Leeuwin Current on the catches from coastal fish stocks is vital for effective fisheries management, in particular being able to interpret whether fluctuations in catches are due to the current or other environmental factors or the impact of fishing on the spawning stock.

Years in which the flow of the Leeuwin Current is strong can be positive for the dispersal of eggs, larvae and juveniles of some fish species and for their subsequent recruitment into fisheries. However, for other species, a relatively strong Leeuwin Current can lead to poorer recruitment.

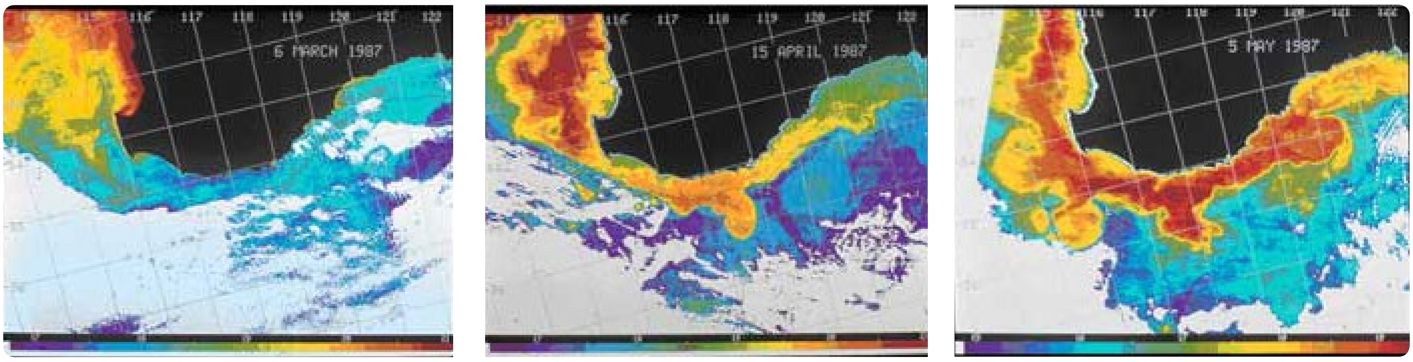
The relationship between the Leeuwin Current and the relative abundance of western rock lobster larvae (called 'puerulus' at the time when they settle on the coast) over the last 40 years is well-documented. In years when the flow of the Leeuwin Current is relatively strong, a higher proportion of larval lobsters return to coastal waters over a larger area.

It takes from three to four years for western rock lobsters to reach legal catch size from the puerulus stage – and there is a direct relationship between the level of puerulus settlement and future catches. In years when the Leeuwin Current is relatively weak, recruitment is usually poorer than when it is strong.

Photo: Sandy Clarke

Western rock lobster puerulus.

Adult Western Australian salmon and Australian herring time their spawning migration to the south-west corner of Western Australia to coincide with the strengthening of the Leeuwin Current during autumn. In years of strong flow, the Leeuwin Current can transport increased numbers of eggs and larvae to juvenile nursery areas along the south coast and into South Australia.



Series of sea-surface-temperature images showing the intensification shown in red of the Leeuwin Current in southern Western Australia during autumn (5 March, 15 April, 5 May 1987). (www.amsa.asn.au/awards/winners_silverjubilee/2006_cresswell_george.php)

However, timing and current characteristics need to be just right. Coastal waters can be too warm for migrating Western Australian salmon schools. For example, in some years the salmon migration may only reach as far north as Busselton and the fish often disappear into deeper offshore areas where waters are cooler.

Some fisheries, such as those for pilchards and Shark Bay scallops, benefit when the Leeuwin Current is weaker, resulting in eggs and larvae remaining near the area where spawning took place. Studies have shown that pilchard eggs and larvae can be dispersed by 140 kilometres in just a matter of days during a strong flow, but may travel only 20 kilometres in weak flows.

Scallop fisheries in Shark Bay have above-average recruitment when the Leeuwin Current is weak, with a higher proportion of larvae remaining in the gulfs of Shark Bay. Variation in water temperatures during the spawning period may also have a part to play in this recruitment.

Human recreation

The Leeuwin Current has an influence on Western Australia's climate. In comparison to those at similar latitudes, the ocean waters that the Leeuwin passes through are warmer, providing for higher-than-expected winter air temperatures and rainfall.

Clear waters and white calcareous beach sands attract humans to pursue a range of recreational pursuits and tourism. Sea-surface-temperatures over the winter months along the WA coastline are much higher than at other locations in the world at the same latitudes.

Surfers in particular take advantage of surfing winter waves and higher sea surface temperatures.

The Leeuwin Current is also much stronger during this time. These warmer-than-expected waters are still attractive for recreational activities, albeit in a wet suit for most people.

Western Australia's world-renowned beaches and high underwater visibility can be attributed in part to the Leeuwin Current. High visibility is generally the norm, with diving enthusiasts having a rich diversity of both tropical and temperate organisms to observe.

The Leeuwin Current influences the composition and presence of marine organisms that are sought along the Western Australian coast by commercial and recreational fishers and ecotourism operations.

Photo: Carina Gemignani

Clear waters allow high visibility in the Abrolhos.

Conclusion

Although a strong Leeuwin Current has been linked with high rock lobster larval numbers in the past, the record low puerulus recruitment in 2008/09 coincided with a strong Leeuwin Current. This has challenged researchers to re-evaluate their understanding of the Leeuwin and seek answers by identifying what other factors may have influenced the puerulus settlement during this period.

It is clear there is still much to learn about the characteristics, variability and complexity in the Leeuwin Current system. The influence and consequences of climate change and frequency of ENSO events are still relatively poorly understood. An improved understanding is crucial in the ongoing management of our fish stocks and the minimisation of disruption to them - and to maximise the resilience of marine ecosystems to climate change.

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Glossary

Benguela Current: a cold ocean current flowing northward along the south-western coast of Africa.

Density: the mass per unit volume of a substance.

Eddy: a water (or air) current, moving against the direction of the main current, especially in a circular motion, i.e. a whirlpool.

Humboldt Current (or Peru Current): a cold ocean current flowing northwards along the western coast of South America.

Indonesian Throughflow: water flow through the Indonesian archipelago to the Indian Ocean driven by south-east trade winds in the Pacific Ocean.

Larvae (larva): the immature form of animals which undergo metamorphosis (a change in form) before becoming a juvenile or adult.

Ocean current: transport of ocean water in a prevailing direction and defined area.

Recruitment: addition of fish to a stock or population as a result of reproduction, migration or growth to legal size.

Settlement: change from a free-swimming form to one that attaches to a substrate

South Equatorial Current: is predominantly a southern hemisphere current that flows westwards across the Pacific, Atlantic and Indian Ocean close to the equator and driven by south-east trade winds.

Southern Oscillation Index: measurement of the atmospheric pressure fluctuations between Darwin and Tahiti in an attempt to indicate El Niño and La Niña episodes.

Tropical: in the southern hemisphere, the seas that lie between the Equator and Tropic of Capricorn.

Upwelling: the process where warm, less-dense surface water is drawn away from the coast by offshore winds and replaced by cold, denser and usually nutrient-rich water brought up from the subsurface.

Acknowledgements

Dr. Alan Pearce, Dr. Nick Caputi and Dr. Rod Lenanton for their factual review and helpful comments on this document. Thanks must also go to Mr Steve Ireland for his input and proofing eye.

FURTHER INFORMATION

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